CHAPTER 6
CONCLUSIONS

1. Three types of canal linings (concrete, exposed geomembrane, and concrete with geomembrane underliner) showed favorable B/C ratios in the range of 1.9 to 3.7 (table 21).

Table 21.—Benefit/Cost ratios of four types of canal linings

Type of Lining	Durability (years)	Maintenance ($/ft^2/yr)	Effectiveness (percent seepage reduction)	B/C
Fluid-applied Membrane	10 - 15 yrs	$0.010	90 %	0.2 - 1.5
Concrete alone	40 - 60 yrs	$0.005	70 %	3.0 - 3.5
Exposed Geomembrane	10 - 25 yrs	$0.010	90 %	1.9 - 3.2
Geomembrane with Concrete Cover	40 - 60 yrs	$0.005	95 %	3.5 - 3.7

2. Each of these linings has advantages and disadvantages. The geomembrane with concrete cover offers the best long-term performance.

   a. Concrete—Concrete has excellent durability but only 70 percent long-term effectiveness. Irrigation districts are familiar with concrete and can easily perform required maintenance.

   b. Exposed Geomembrane—Exposed geomembranes have excellent effectiveness (90 percent), and the lowest initial construction cost. However, they are susceptible to weathering and damage from animal traffic, construction equipment, and vandalism. Also, irrigation districts cannot readily maintain exposed geomembranes because they are not familiar with geomembrane materials and the special seaming equipment needed to perform repairs.

   c. Concrete with Geomembrane Underliner—The geomembrane underliner provides the water barrier and the concrete cover protects the geomembrane from mechanical damage and weathering. The system effectiveness is estimated at 95 percent. The irrigation district can readily maintain the concrete cover but does not have to maintain the geomembrane underliner.

3. **New Test Sections—**The authors are hesitant to draw too many conclusions regarding some of the newest test sections. While some of these test sections look very promising, more time is needed to evaluate them. These test sections include:

   Buried GCL (test section O-1)
   Exposed EVA geocomposite (test section BI-1)

Exposed white HDPE (test section BU-1)
Exposed metallized PE (test section LO-1)
Exposed, wet-applied, polyurethane geocomposite (test section TF-1)

4. **Maintenance—**Through 10 years, maintenance costs have been relatively low for all the lining alternatives. Generally, exposed geomembranes require about twice the maintenance of concrete linings ($0.010 vs. $0.005/ft^2/yr). For all lining alternatives, B/C analysis shows that every $1 spent on maintenance returns $10 to $20 in conserved water by increasing effectiveness and design life. ***Therefore, more emphasis should be placed on maintenance.***

CHAPTER 7
FUTURE STUDIES

The 34 test sections range in age from 1 to 10 years. Reclamation plans to revisit these 34 test sections in another 3 to 5 years to further assess their performance, especially the newest test sections, which have only been through one or two irrigation seasons.

1. Additional Test Sections—Reclamation will continue to collaborate with manufacturers to construct additional test sections to evaluate new materials and techniques. New test sections being considered include Polyacrylamide (PAM), Soil Cement, and bottom-only lining. Reclamation is pursuing a cooperative agreement with Denver Water to construct these test sections on Denver's Highline Canal.

    a. PAM is a spray-applied polymer emulsion than can be applied at very low unit costs. PAM acts as a flocculent and forms a "slime" layer on the canal invert. This layer of polymer slime and flocculated soil particles forms a seal on the canal prism, significantly reducing seepage. The effects of PAM are somewhat temporary, and PAM is usually re-applied once or twice a year. The Uncompaghre Valley Water Users Authority (UVWUA) has been experimenting with PAM, and Reclamation will be assisting UVWUA with a scientific analysis of PAM costs, effectiveness and durability.

    b. Soil Cement is created in the canal prism by in-situ mixing the canal native soils with cement and water. Reclamation is pursuing a cooperative agreement with PCA to research this material.

    c. Bottom-only lining consists of placing a geomembrane on the canal invert and covering it with 6 to 12 inches of soil. The side slopes are left unlined. Pervious research has shown that bottom-only lining can be 20 to 50 percent effective. Bottom-only lining can be cost effective because the bottom is the easiest part of the canal to line. Bottom-only lining is also aesthetically pleasing because the geomembrane is buried in the invert and not visible from the canal bank.

2. Repairs—The irrigation districts often do not have the equipment or expertise to perform repairs on the exposed geomembrane test sections. Reclamation has purchased a small hot-air welder to loan out for making repairs. This small, hand-held welder is suitable for small repairs on most of the exposed geomembranes, including HDPE, LLDPE, PP, and PVC.

3. Addition costs comparisons - to help compare the materials in this study with other lining alterations, additional cost comparisons are needed for traditional lining materials, such as buried pipe and buried geomembranes.

Tulelake Irrigation District - The First

Klamath Falls Field Office was the first Reclamation office to prepare geomembrane canal-lining specifications using this study as a guide. Tulelake Irrigation District (T.I.D.), which is located in the Kalamath River Basin on the Oregon - California border, was declared in extreme drought conditions during the summer of 2001 and did not receive its allotment of irrigation water for that year. To ease the water shortage, irrigation wells were drilled and the water pumped into the canal for delivery to the ranchers. The cost for this water to the Bureau was from as low as $20.00 per acre foot to as high as $55.00 per acre foot. The average cost was $37.50 per acre foot. T.I.D. has a two tiered pricing plan. If irrigation water is delivered as it has been in the past, the rancher would pay an average cost of $14.00 per acre foot.

T.I.D. recognized that water losses due to seepage were a problem. The M-2 Lateral diverts water from the M - Main Canal. Because of the drought in this region, T.I.D. approached Reclamation for assistance with lining a portion the M-2 Lateral. The portion of the lateral that T.I.D. wanted to line was 2.3 miles long, and had a cross section of about 26 feet.

The Klamath Falls Area Office contacted the Pacific Northwest Regional Office Water Conservation Center for assistance. Reclamation met with T.I.D. representatives and convinced them that a geomembrane lining material would work and told them that Reclamation would put out a specification. Materials and training for installation would be provided by the material supplier, and the canal preparation and the labor for installation would be furnished by T.I.D. It was determined by the Procurement Branch in the Mid-Pacific Region that the appropriate way to bid this job would be to use the Simplified Acquisition Procedures. The job description was written and advertised in the Commerce Business Daily. (See appendix F, which includes the notice, the questions asked after the site visit, and sample evaluation sheets.) A site visit was held after release of the advertisement, and questions and answers were fielded at the end of the visit. Nine companies attended the site visit. In all, 12 companies bid on this job. Jim's Water Gardening, of Salem Oregon, was selected to do the work. The geomembrane proposed was a 45-mil EPDM manufactured by Firestone Building Products. Before the material arrived, T.I.D. began preparing the canal using their equipment. When the material arrived at the site, T.I.D. was ready to begin the installation. T.I.D. had about 10 employees, included the heavy equipment operators, available for the installation. When the installation started, T.I.D. was given instructions on how to place the material and seam the panels together. T.I.D. completed the job in about 4 weeks. (This included time that was needed to fix another problem that had occurred).

Reclamation made an assessment of the seepage rate and the B/C ratio for this job. The average seepage rate for this area was estimated to be about 0.65 ft^3/ft^2/day. If the cost of water for T.I.D. was $14.00 per acre foot, the B/C ratio was about 1.4; however, if the cost of water was $37.50, which was the current market price, the B/C ratio would be 3.6.

Canal Lining Costs for Tulelake Irrigation District M-2 Lateral

Description	Lining Material				Subgrade Preparation and Installation $ / ft^2	Total $ / ft^2
	Geomembrane $ / ft^2	Geotextile $ / ft^2	Shotcrete $ / ft^2	Other Cost $ / ft^2		
Exposed 45-mil EPDM	$0.27	$0.09			$0.11	$0.47

Tulelake Irrigation District
Exposed 45-mil EPDM Geomembrane

Photograph 1.—M-2 Lateral before lining.

Photograph 2.—M-2 Lateral after shaping.

Tulelake Irrigation District
Exposed 45-mil EPDM Geomembrane

Photograph 3.—Geotextile in place and the geomembrane being place over it.

Photograph 4.—Tulelake Irrigation District personnel pulling the lining material up the side slope.

Tulelake Irrigation District
Exposed 45-mil EPDM Geomembrane

Photograph 5.—T.I.D. personnel seaming the panels using a solvent and a 6-inch wide tape.

Photograph 6.—View of one of the cutoff trenches. Concrete was placed in the trench dry. As water gets in the bag, the concrete hardens and acts as an anchor.

Tulelake Irrigation District
Exposed 45-mil EPDM Geomembrane

Photograph 7.—View of the cutoff ditch around a turnout structure. The same procedure was used here as in photograph 6.

Photograph 8.—Completed geomembrane installation.